

The Long Period AM Her-like Cataclysmic Variable **RXJ051541+0104.6**

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ABSTRACT

We report the discovery of a new cataclysmic variable system, RXJ051541+0104.6. The optical spectrum has a blue continuum with superposed H I and He I and II emission lines. The soft X-ray spectrum is well fit with a 50 eV black body. The X-ray and optical data are suggestive of an AM Herculis system. The X-ray light curve shows extreme variability on timescales of seconds, and suggests an orbital period of order 8 hours, nearly twice that of the longest catalogued AM Her period. When bright, the X-ray light curve breaks up into a series of discrete bursts, which may be due to accretion of dense blobs of material of about 10^{17} gm mass.

Subject Headings: stars: cataclysmic variables – X-rays: stars

1. Introduction

As part of a program to study the spatial distribution of low mass pre-main sequence stars in the Orion OB1 association, we obtained the ROSAT PSPC observation RP200930. This image is centered at $5^h14^m24.0^s +1^\circ42'0''$ (J2000), to the west of the Ori OB1a association, and was meant to serve as a control field, far from the region where we expected to find low mass association members. The standard SASS processing yielded 37 X-ray sources. In the course of obtaining optical spectra of the stellar counterparts of these X-ray sources, we discovered a previously unknown cataclysmic variable with extreme X-ray variability.

Cataclysmic variables are semi-detached binary systems, with accretion from a low mass non-degenerate star onto a white dwarf. The cataclysmic variables come in a number of classes, defined by accretion rates and accretion geometry (e.g., Córdova 1993). Among these are the various types of novae and nova-like systems and the magnetized systems, the polars and intermediate polars. Polars and intermediate polars are often discovered by virtue of their X-ray emission.

The polars, or AM Her systems (e.g., Cropper 1990), are strongly magnetized systems with the white dwarf rotating synchronously on the orbital period. There is no evidence for accretion disks in polars: the accretion is along magnetic field lines onto the magnetic poles of the white dwarf. Orbital periods are generally less than 2 hours, but have periods up to 4.6 hours (RXJ1313-32; Ritter & Kolb 1993). Polars are strong soft X-ray sources, and 20 such systems have been discovered in the ROSAT all-sky survey (e.g., Beuermann & Schwöpe 1994), more than doubling the previously-known population. The intermediate polars, or DQ Her systems (e.g., Patterson 1994), are also magnetized, but the white dwarf periods are much shorter than the orbital periods, presumably because the magnetic fields are too weak to enforce synchronization. Accretion is through a disk. Periods tend to

be longer than for the polars, and the X-ray emission tends to be dominated by a hard bremsstrahlung component.

This new cataclysmic variable exhibits several puzzling characteristics, which we discuss below. The X-ray light curve resembles that of a single-poled polar², yet the period is much longer than any known polar. The soft X-ray and optical spectra are more similar to those of polars than of intermediate polars. The X-ray emission is highly variable; when bright, the emission breaks up into a discontinuous series of discrete bursts. This behavior is unlike that seen in any cataclysmic variable discussed to date, but is expected if the accretion consists not of a smooth flow but of discrete blobs of material (e.g., Frank, King, & Lasota 1988). This object may provide clues to the evolution of cataclysmic variables, and the relation of the polars to the intermediate polars.

2. X-ray Observations

The X-ray data were obtained using the *Röntgen Satellite* (ROSAT; Trümper 1983; Pfeffermann *et al.* 1987; Aschenbach 1988). Observation RP200930 was obtained in two segments; 3.7 Ksec between 1992 September 11 and 19, and 6.1 Ksec on 1993 February 27 (observation times are provided in Table 1). The total exposure time was 9779 sec. The object, RXJ051541+0104.6, was detected in both segments. It lies 42 arcmin off-axis. Because of the large off-axis distance, the SASS ML source detection algorithm was not run, and no formal uncertainties on the source location were provided. The mean X-ray

²We use this term to describe a polar with an X-ray light curve similar to that of VV Pup, where there are two magnetic poles but only the principle pole is occulted by the body of the white dwarf.

source position, weighted by the number of counts in the source, is $5^h15^m40.3^s +1^\circ4'33.9''$ (J2000). No catalogued X-ray source or close binary system is known at this location.

We analyzed these data using the RX package, an IDL-based ROSAT data analysis system (Walter 1994). We extracted the source counts within a circle of 225 arcsec radius centered on the source. The background was extracted from within an annulus between 225 and 675 arcsec from the source, excluding a wedge containing another X-ray source. The extraction areas were normalized using the PSPC exposure map. The X-ray source is fairly bright, with a mean vignetting-corrected count rate of 0.21 ± 0.006 counts s⁻¹ in the PSPC. A net total of 1028 source counts were extracted.

The source also appears at the edge of a second image, RP700422, 56 arcmin off-axis. This is a day-long pointing obtained while ROSAT was in the reduced-pointing mode. The image contains 24.5 Ksec of data in an 85.7 Ksec interval. We extracted 2972 photons from this source using a 3600 arcsec circle and an 18 arcmin radius background annulus. The source is visibly truncated by the edge of the detector, and wobbles out of the field of view about 100 of every 400 seconds, so we cannot place much confidence in either short-term variability (less than the typical 1000 sec integration each orbit) or the spectrum. The background light curve shows strong soft enhancements toward the ends of many intervals. We have not edited these data out because they have no significant effect on the background-subtracted light curve, and because we did not attempt a spectral analysis.

2.1. X-ray Variability

The light curve from observation RP700422 is shown in Figure 1. The data show a repeating pattern suggestive of a period of about 8 hours. Observations from low Earth orbit can suffer from aliasing with the \sim 94 minute spacecraft orbit. During RP700422,

observations were obtained on nearly every orbit, for about 3000 seconds (often in two segments, with a central gap due to SAA passages). Observation RP200930 contains two 3000 second observation intervals (OBIs). The source is seen to be low (count rate less than the mean rate) about 60% of the time, and high the remaining time. If the light curve is repeatable, then we can rule out any periods less than about 2.1 hours because we see no significant differences in mean activity level within any single orbit. The best fit period, from folding the RP700422 light curve on itself, is 8.05 ± 0.1 hours (Figure 2). The RP200930 data are fully consistent with this period, but cannot be used to determine a more precise period because the cumulative period uncertainty over the 6 months between observations greatly exceeds the period.

The data from observation RP200930 are more suited to detailed time analysis. In 1992 September the intensity was low, at a rate of $0.12 \text{ counts s}^{-1}$ (Figure 3). One significant flare is superposed on the light curve. The source is not constant. The character of the emission changed dramatically during the second observation. The source was fairly constant during the first OBI. Following an 8.3 Ksec gap in the observation, the source became highly variable (Figure 4). The mean count rate quadrupled. Significant variations exist to timescales shorter than 2 seconds; on this scale the instantaneous count rate reaches 15 counts s^{-1} .

We verified that this extreme variability was indeed a property of the X-ray source, and not a detector artifact, by examining the light curves of other X-ray sources in the field. None exhibit significant variability during this interval. The background count rate in the annulus surrounding the source is similarly constant. Because the source is well off-axis, the point spread function overlaps several of the wires of the coarse window support mesh at all times. The spacecraft wobble has no significant effect on the observed light curve.

We searched for periodicities within the individual OBIs using FFT and period-folding

techniques. No significant periodicities were found on timescales of a few seconds to 1000 seconds.

2.2. The X-ray Spectrum

We binned the background-subtracted PI (pulse height invariant) data from RP200930 into the 34 SASS channels. After excluding channels 1-2 and 33-34, we fit the source counts using XSPEC version 8.40. The fits are summarized in Table 2, and shown in Figure 5. We found acceptable fits for a blackbody spectrum with $kT=50$ eV or a powerlaw spectrum with $\alpha=8$. We found no acceptable fit for a thermal plasma. The spectrum is highly absorbed, which suppresses much of the uncertainty due to gain calibration in the lowest energy channels. In the following discussion, we will refer only to the blackbody spectral fits, because the soft X-ray emission from cataclysmic variables is expected to, and indeed is observed to be, blackbody in character (e.g., Lamb 1985).

We separately fit the data obtained when the the source was “quiescent” and when the source was “active”. There was no significant difference in either the soft X-ray temperature or the absorption column. When the source was active, we subdivided the data into a bright source (instantaneous count rates >2 c s $^{-1}$) and a faint source; again, there were no significant differences in the spectral fits.

We did not attempt to fit the data from RP700422 because of the extreme distance off-axis. A visual inspection of the PI pulse-height distribution shows no significant differences from that of the data actually fit.

We see no evidence of a hard X-ray bremsstrahlung component in these data. We fit the spectrum with two spectral components, a black body component plus a hard bremsstrahlung component. The inclusion of the hard component led to a modest reduction

in χ^2 (Table 2), but there was no significant change in the blackbody temperature, and the bremsstrahlung temperature and normalization are unconstrained. Over the energy range the PSPC is sensitive to, we can place no meaningful limits on either the hard X-ray flux or the ratio of L_{bb}/L_{brems} in this object.

3. The Optical Counterpart

A finding chart is presented in Figure 6. The optical counterpart (marked) is the westernmost and brighter of two stars near the X-ray position; it is not in the HST Guide Star Catalog (Lasker *et al.* 1990). We determined the J2000 optical position, $5^h15^m41.42 \pm 0.01^s +1^\circ4'40.7 \pm 0.4''$, relative to 3 nearby stars in the guide star catalog. The star is about 18 arcsec from the weighted mean X-ray position. There is a fainter star about 15 arcsec to the east. The target was optically identified by its spectrum.

3.1. The Optical Spectrum

The optical spectra (Figures 7 and 8) were obtained using the KPNO 2.1m telescope with the GOLDCAM camera and grating 47. The red spectrum was observed on 1993 January 1. It covers the $\lambda\lambda 5500-7600\text{\AA}$ interval at about 3\AA resolution. The blue spectrum was observed on 1994 January 29. It covers the $\lambda\lambda 4000-5000\text{\AA}$ interval at about 1.5\AA resolution. The data were reduced and flux-calibrated using the IRAF APEXTRACT and ONEDSPEC packages. The spectra were extracted using variance-weighting within APALL. Subsequent analysis has been done in IDL using the ICUR spectral analysis package.

The red spectrum is the average of two 900 second exposures obtained under good seeing with non-photometric conditions. The spectrum was placed on a relative flux

scale using the stars HD17520, HD86986, HD109995, and HD217086 as standards. The continuum is quite blue. The strongest line is H α , with an equivalent width $W_\lambda(H\alpha) = -30\text{\AA}$. The line is asymmetric, with emission extending some 40\AA towards the blue. The line can be fit as two Gaussians, with $\sigma = 6$ and 20\AA and the broad component centered 7\AA to the blue of the narrow component. The other prominent emission lines are He I $\lambda 5876$, 6678 , and 7065\AA . The brighter two of these lines have profiles similar to H α . There is a prominent broad Na D absorption feature redward of He I $\lambda 5876$. Line measurements are summarized in Table 3.

The blue spectrum is underexposed. It is an 1800 second exposure obtained with the target between 2 and 3 hours west of the meridian. The seeing was poor; the night was far from photometric. The 3 individual exposures were averaged to produce the final spectrum. The flux standard Feige 34 was used to place the star on a relative flux scale. Three emission lines (H β , H γ , and He II $\lambda 4686$) are visible in the unsmoothed spectrum. Equivalent widths of the lines are compiled in Table 3.

We did not obtain spectra of the faint star to the east.

3.2. Optical Photometry

Optical photometry was obtained on 3 separate photometric nights, 1993 December 5, 15, and 17 (Table 4). The observations on December 5 were made from Kitt Peak using the 0.9 meter, the Bessell filters from the Harris filter set and the T2KA CCD detector. The later observations were made with the 31" telescope on Anderson Mesa which is jointly operated by Lowell Observatory and Northern Arizona University. These observations were made with standard B through I Bessell filters and a Photometrics liquid nitrogen cooled CCD. All data were processed using IRAF for general debiasing and flat-fielding. The

digital photometry was undertaken using IRAF with a mean extraction aperture size of 5 arcsec. Photometry was calibrated by comparison with standards measured by Landolt (1983). Magnitudes and colors are presented in Table 4.

Taking the mean V magnitude to be 15.5, the $\frac{f_X}{f_V}$ ratio is about 6, where f_X is the integrated, dereddened flux from the 49 eV black body. When faint, the system appeared redder. It is possible that the 5 December observations caught an eclipse of the principle accretion pole, and that the light is dominated by the secondary. The colors, however, are not those of a star, so some blue continuum must have been present.

Near IR Photometry was obtained on the 1993 October 30 using the Simultaneous Quad Infrared Imaging Device (SQIID) on the 1.3 meter telescope at KPNO. Three 180 second exposures were taken of the target. Routines written by the authors in IDL were used to subtract the dark current and sky backgrounds from the raw frames as well as to perform the flat-fielding and coaddition to create final frames. The near-infrared photometry was calibrated by comparison with standards measured by Elias *et al.* (1982). The near-IR colors are consistent with a hot blackbody ($T \gtrsim 8000\text{K}$), and not with emission from a cool secondary. Note that the near-IR and optical photometry were obtained at different epochs.

Further optical photometry has been obtained using the Stony Brook 14" telescope with a Santa Barbara Instrument Group ST-6 CCD from 1994 March 18-25. These data were obtained solely to look for evidence of eclipses, using 4 other stars in the field as photometric standards. We observed a 7.6 x 5.7 arcmin field. The average seeing at SUNY at Stony Brook is 3-5 arcseconds. The images consist of sixteen coadded frames with 15 second integration time each, giving the final image an integration time of 4 minutes. The images were flat-fielded and dark-corrected using SBIG software. IRAF was used for the photometric measurements. No filters were used. The magnitude of the target is

near the practical limit for observing from Stony Brook, and because of the time of year, the observations were made at high air mass (and in the direction of the sky glow from New York City). We obtained 13 images over a 6 day span. Six images were taken in a 110 minute interval on 1994 March 25; the other 7 images were obtained between 1994 March 19 and 24. We see no convincing evidence for variability at the $\pm 25\%$ level. We detected no eclipses. For a period of ~ 8 hours, we sampled essentially the same phases (<0.25 of the full orbit) during the entire run.

4. Discussion

The optical and X-ray spectra, and the large $\frac{f_X}{f_V}$ ratio suggest that this object is a magnetic cataclysmic variable (e.g., Mason 1985, Cropper 1990). The rapid X-ray variability requires a compact object. The relative strengths of the He II $\lambda 4686$ and H β emission lines (Liebert & Stockman 1985), and the strength of the soft-X-ray emission, are suggestive of an AM Her variable. The folded X-ray light curve, shown in Figure 2, is similar to the X-ray light curve of VV Pup (Osborne *et al.* 1984), though on a much longer period. The light curve shows that the quiescent interval lasts about half the period, followed by a smooth increase to a maximum about 7 times brighter than the quiescent level. We assume this period is the orbital period of the system. Based on the light curve, we consider it likely that this object is a polar or an intermediate polar wherein the principle accreting pole is occulted every stellar rotation.

No currently catalogued AM Her system has a period longer than 4.6 hours (Ritter & Kolb 1993). If this is indeed an AM Her system, with a synchronously-rotating white dwarf, then the magnetic field strength must be quite large to force circularization at an 8 hour orbital period. Using Patterson's (1994) scaling law, B must be of order 7×10^8 G if the

accretion rate and the mass of the white dwarf are typical of magnetic cataclysmic variables. Such a field strength, or even a considerably weaker field, should produce easily-visible circular polarization. If the white dwarf’s rotation is not synchronous, then this object may represent the progenitors of an AM Her-type system. This object may provide some insights into the relation between the polars and the intermediate polars.

Recently, Garnavich *et al.* (1994) reported that the system is an eclipsing magnetic cataclysmic variable, with a 7.98 hour orbital period. They estimated a magnetic field strength of up to 5.5×10^7 G from the strength of the cyclotron emission humps. This is fully consistent with our characterization based on the X-ray light curve. The magnetic field is weaker than predicted from Patterson’s scaling law, suggesting that either the white dwarf is about half the mass of that in a typical magnetic cataclysmic variable, that the system is not in synchronous rotation, or that the scaling law breaks down for large separations.

The most unusual aspect of this object is the X-ray variability on short timescales. Figure 9 shows a segment of the active interval during RP200930. Note that the X-ray emission breaks up into a sequence of bursts with typical duration of 10 seconds. There is no evidence for a steady component underlying the bursts. The bursts are not periodic, but there is a mean separation time between them of order 30 seconds. These appear comparable to the quasi-periodic bursts seen in AM Her by Tuohy *et al.* (1981), although in AM Her the bursts are superposed on a strong background. Short bursts have also been seen in BL Hyi (Beuermann & Schwope 1989). The detected flux in the typical burst is 3×10^{-9} erg cm $^{-2}$, yielding a burst energy

$$E_b \sim 1.3 \times 10^{34} D_{200}^2 \text{ erg}$$

where D_{200} is the distance to the source in units of 200 pc. The mass of the accreting blob, if all its kinetic energy is released in the soft X-rays, is

$$M_{blob} = 1.0 \times 10^{17} D_{200}^2 R_9 / M_1 \text{ gm},$$

where R_9 and M_1 are the radius and mass of the white dwarf in units of 10^9 cm and one solar mass, respectively.

The soft blackbody component is generally thought to be attributable to thermal reprocessing of harder bremsstrahlung and cyclotron X-ray emission. The discrete bursts are suggestive of blobby accretion models developed by Kuipers & Pringle (1982) and Frank *et al.* (1988). The blobs possess sufficient ram pressure to plunge deep into the photosphere before shocking. The hard X-ray bremsstrahlung radiation suffers multiple scatterings and emerges as the soft blackbody component seen in many AM Her systems (e.g., Lamb & Masters 1979).

We can estimate the mean mass accretion rate, \dot{m} , and the fractional area, f , undergoing accretion by equating the blackbody luminosity

$$L_{BB} = 4\pi R^2 f \sigma T^4,$$

the observed X-ray luminosity (dereddened and extrapolated over the entire wavelength range of the blackbody emission, using the spectral fit)

$$L_X = 4\pi d^2 f_x,$$

and the accretion luminosity

$$L_{acc} = GM\dot{m}/R,$$

where we assume that all the accretion luminosity is radiated into the blackbody component. Plugging in the observed temperature and observed X-ray flux, $L_{BB} = 7.5 \times 10^{37} R_9^2 f$, $L_X = 7.5 \times 10^{31} \frac{f_x}{\langle f_x \rangle} D_{200}^2$, and $L_{acc} = 1.3 \times 10^{17} M_1 \dot{m} / R_9$. Rearranging these, we find that

$$f = 1.0 \times 10^{-6} \frac{f_x}{\langle f_x \rangle} \left(\frac{D_{200}}{R_9} \right)^2, \text{ and}$$

$$\dot{m} = 5.8 \times 10^{14} \frac{f_x}{\langle f_x \rangle} D_{200}^2 \frac{R_9}{M_1} \text{ gm s}^{-1},$$

where f_x and $\langle f_x \rangle$ are the instantaneous and mean X-ray fluxes. For a typical luminosity of $L_{33} = 10^{33} \text{ erg s}^{-1}$,

$$\frac{f_x}{\langle f_x \rangle} D_{200}^2 = 13.3 L_{33},$$

$$f = 1.3 \times 10^{-5} L_{33} R_9^{-2}, \text{ and}$$

$$\dot{m} = 7.7 \times 10^{15} L_{33} R_9 / M_1$$

The instantaneous luminosity varies by nearly two orders of magnitude, but we see no evidence for significant changes in the temperature. Therefore, increases in luminosity must be due to increases in \dot{m} and f . Both scale linearly with the instantaneous flux. This suggests that all the blobs penetrate to sufficiently large optical depths to thermalize completely. The more massive blobs may penetrate deeper and illuminate a larger fraction of the surface area.

The wide binary orbit can accommodate a relatively luminous secondary. The Na D absorption (Figure 7), coupled with the lack of strong TiO absorption bands, suggests a secondary with a G to late-K spectral type. The Na D absorption could be partly interstellar, but are the strongest metallic features in the red in G-K stars; our spectrum is too noisy to detect the $\lambda 6495\text{\AA}$ blend. The colors observed on 1993 December 5 are fairly red, but are not consistent with any cool star. If the secondary has the colors of a normal dwarf, and the light is the sum of the secondary and a blue continuum, then the secondary cannot be earlier than about spectral type K2. Garnavich *et al.* (1994) obtained an M0 spectral type for the secondary from a spectrum during eclipse.

This system provides strong evidence for accretion through discrete blobs. In this system the blobby accretion may not be just sporadic, as has been seen in other polars, but

may be the normal state. Accretion is not expected to produce a smooth hydrodynamic flow, and larger separation between components may give more time for the instabilities to grow and to produce better-defined blobs than in the shorter-period systems. If the fraction of the accreting matter in discrete blobs is large, as suggested by the X-ray light curve, then the hard X-ray flux from this object should be minimal.

In conclusion, RXJ051541+0104.6 is a magnetic cataclysmic variable with a period over twice as long as the longest known AM Her system. Further studies may reveal much about both the accretion processes in close binaries and the evolution of cataclysmic variable systems.

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Table 1: X-ray Observation Log

Observation	Pointing (J2000)	date	start	stop	N ^a	seconds
			UT			
RP700422	5 16 11.0 +0 09 0.1	1991 Sept 18	16:44	16:33 ^b	35	24493
RP200930	5 14 24.0 +1 42 0.0	1992 Sept 11	19:39	20:05	1	1488
		1992 Sept 19	5:39	5:38	2	2165
		1993 Feb 27	12:22	16:25	3	6126

^aNumber of OBIs containing good data.

^bObservation ended on 1991 September 19.

Table 2: Summary of Spectral Fits

model	n_H	$P1^a$	kT_{brems}	χ^2	DoF ^b
	cm^{-2}				
blackbody	$5.4 \pm 1.3 \times 10^{20}$	49 ± 5	—	30.9	27
power law	$1.0 \pm 0.2 \times 10^{21}$	8.2 ± 1.1	—	25.4	27
bb+brems	$6.0 \pm 1.6 \times 10^{20}$	46 ± 6	13 ± 273	25.8	25

^aSpectral fit parameter: kT (ev) for the blackbody fit, or α for the power law fit.

^bDegrees of freedom for the spectral fit.

Table 3: Summary of Line Measurements

line	λ	date	$W_\lambda(\text{\AA})$
H I	4340	29 Jan 1994	-25:
H I	4860	29 Jan 1994	-20:
H I	6563	1 Jan 1993	-30
He I	5876	1 Jan 1993	-5.
He I	6678	1 Jan 1993	-5.
He I	7065	1 Jan 1993	-3.5
He II	4686	29 Jan 1994	-22:
Na I	5890	1 Jan 1993	3.3

Table 4: Summary of Photometric Observations

Date (UT)	V	U-B	B-V	V-R	R-I
1993 December 5.40	16.05±.03	-0.42±.06	0.61±.06	0.49±.04	0.48±.05
1993 December 15.21	15.58±.02	—	0.21±.04	0.52±.02	0.24±.04
1993 December 17.21	15.47±.02	—	0.31±.05	0.30±.02	0.42±.02
Date (UT)	K	J-K	H-K		
1993 October 30.32	13.94±.06	0.01±.06	0.00±.02		

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Figure Captions

Figure 1. The soft X-ray curve of RJ051540+0104.6 during the 1991 September observation (RP700422). The data are binned in 800 second bins. Background has been subtracted. The mean count rate is indicated by the dashed line. The source was near the edge of the field, and wobbled out of the field of view for 100 of every 400 seconds (see text); these count rates have not been corrected for this effect. The overall light curve suggests about an 8 hour periodicity.

Figure 2. The X-ray flux from RP700422 (Figure 1) folded on an 8.05 hour period. Two periods are plotted for clarity; zero phase is arbitrary.

Figure 3. The “quiescent” light curve during the first 5 OBIs of observation RP200930 from 1992 September and 1993 February 27. The background-subtracted, vignetting-corrected count rate is plotted in 100 second time bins. The short dashed horizontal line represents the mean count rate. The two dashed vertical lines represent data gaps of approximately 8 days and 5.5 months, respectively. The source is variable.

Figure 4. The erratic light curve seen during the last OBI of observation RP200930, in 30 second bins. The source is highly variable, with significant stretches of zero intensity.

Figure 5. The X-ray spectrum from RP200930 with the best fit blackbody spectrum ($kT=49$ eV) overplotted.

Figure 6. Finding chart. This image is a 20 second V-band observation taken with the KPNO 0.9m on 1993 December 5. The pixel size is ≈ 0.7 arcsec. The figure is ≈ 4.7 arcmin on a side. North is up and east is to the left. The cataclysmic variable is marked.

Figure 7. The blue spectrum, with a resolution of about 1.5\AA , after smoothing with a 2\AA FWHM Gaussian. The prominent emission lines are H γ , He II $\lambda 4686$, and H β . The narrow spikes atop H γ and at 5000\AA may be due to cosmic rays.

Figure 8. The red spectrum, with a resolution of about 3\AA . Note the blue continuum. He I and H α emission is prominent. Na D is in absorption, but no other features attributable to a cool secondary are visible. If Na D is from a cool secondary, the spectral type cannot be later than mid-K because of the absence of TiO absorption bands.

Figure 9. The X-ray bursts seen in part of the observation shown in Figure 4. The data are binned into 2 second time bins. Error bars are omitted for clarity (after the vignetting correction, single photons in a 2 second bin contribute 0.7 counts s^{-1}). Negative excursions are subtracted background photons. The mean count rate (the dashed horizontal line) corresponds to just under one photon per time bin. The bursts appear symmetric, with durations <10 sec and peak fluxes over 2 orders of magnitude above the “quiescent” level. The bursts are not superposed on a steady source.

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